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EQUATIONS FOR THE CALCULATION OF  
N- AND P-LOAD ON SURFACE WATERS

ir. J.H.A.M. Steenvoorden

Projectgroep Zuidelijke Peel 21

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## 1. INTRODUCTION

During the workshop of the ZUPE modelling group in january 1983 a general approach has been developed for the analysis of alternatives for regional water management (DRENT, 1983). This report gives most of the tools in the field of surface water quality as far as nitrogen and phosphorus is concerned.

The nutrient load of surface and groundwaters is the result of inputs from various sources, which will be dealt with in the next paragraphs. An overview is given in figure 1.

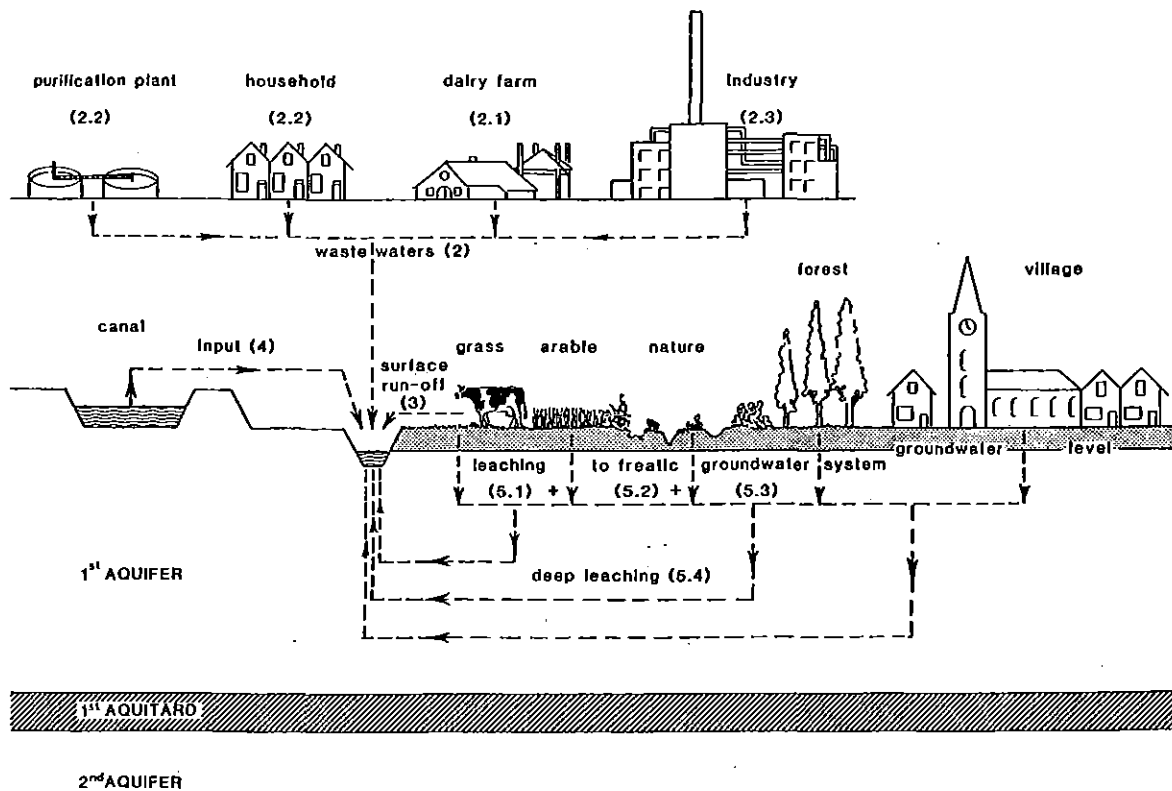


Fig. 1. Picture of the polluting sources in a certain region. Between brackets the chapter is given which deals with a certain source

## 2. PRODUCTION OF WASTE WATERS

The production of waste waters plays a role for the following categories of activities:

- on dairy farms waste waters are the result of cleaning milking machines and cooling tanks
- in houses waste waters originate from toilets and washing machines for laundry and kitchen-ware
- industrial activities might be of importance in some areas
- manure and silage heaps can produce effluents with high N- and P-concentrations.

This source will be neglected as the manure is stored in covered pits in general and the silage heaps are covered with plastic sheets.

So the inputs from these sources will be small in general.

### 2.1. D a i r y w a s t e w a t e r

Waste water from dairy farms consists of cleaning water from milking machines and cooling tanks. This waste water contains detergents and remainders of the milk. The N- and P-content of the cleaning agents shows wide variations from farm to farm depending on the products used. Total losses are not clearly influenced by the size of the farm. Total average production per farm amounts:

$$\hat{N}_r^{dai} = h_r^{dai} \times 4.5 \quad (\text{kg N/year}) \quad (1)$$

$$\hat{P}_r^{dai} = h_r^{dai} \times 6.0 \quad (\text{kg P/year}) \quad (2)$$

in which:

$\hat{N}_r^{dai}$  = total N production in dairy waste waters in region r  
 per farm (kg N.year<sup>-1</sup>)

$h_r^{dai}$  = amount of dairy farms in region r

$\hat{P}_r^{dai}$  = total P production in dairy waste waters in region r  
 per farm (kg P.year<sup>-1</sup>)

The fate of the produced dairy waste waters can differ from farm to farm. An inventory among 25 dairy farms in the Southern Peel region learned that on 60% of the farms these waste waters were added to the slurry pit and were used as a fertilizer. The remaining 40% of the farms disposed the waste water into ditches which are connected with the local drainage system. The load on surface water can be calculated by using the equations:

$$N_r^{\text{dai}} = f_r^{\text{dai}} h_r^{\text{dai}} \times 4.5 \quad (\text{kg N.year}^{-1}) \quad (3)$$

$$P_r^{\text{dai}} = f_r^{\text{dai}} h_r^{\text{dai}} \times 6.0 \quad (\text{kg P.year}^{-1}) \quad (4)$$

in which:

$f_r^{\text{dai}}$  = the fraction of dairy farms in region r with dairy waste water disposal on the local drainage system.

## 2.2. Waste waters from households

Waste waters from households can reach the surface waters via two transport ways:

- via effluents from purification plants
- via discharge of the waste waters on local drainage systems in the direct neighbourhood of houses

A problem which has to be solved in this chapter is the calculation of the number of persons living in a house or in a region. In general the Regional Policy Making Authority (RPMA) will have information on the number of houses which is connected to the sewerage system for the purification plant. No information will be available on the number of persons living in each house. Therefore the assumption is made for this study that a fixed amount of persons will be living in each house. An inventory in a part of the region learns that this number can be put on 4.5, so:

$$(\text{POP})_r = n_r^h \times 4.5 \quad (5)$$

in which:

$n_r^h$  = number of houses in region r

The values for the production of N and P in the different sources found in literature are in general:

	N (kg/pers/year)	P (kg/pers/year)
toilet water	4.4	0.55
laundry washing machine	-	0.75
kitchen ware washing machine	-	?

In the Southern Peel area an enquiry has been organized to collect information about the consumption of detergents and the fate of the waste water. The consumption of detergents appears to be lower than the figures given in literature (OOSTEROM, 1983) and therefore the values in table 1 will be used in the Southern Peel study area.

Table 1. Average production of N and P per person in the waste water from households and symbols used for the different sources

	N (kg/pers/year)	Symbols	P (kg/pers/year)	Symbols
toilet water	4.4	$\hat{N}^{to}$	0.55	$\hat{p}^{to}$
laundry washing machine	-		0.55	$\hat{p}^{la}$
kitchen ware washing machine	-		0.15	$\hat{p}^{kw}$
Total	4.4	$\hat{N}^{ho}$	1.25	$\hat{p}^{ho}$

The total production of N and P in waste water from households amounts:

$$\hat{N}_r^{ho} = \hat{N}_r^{to} \quad (6)$$

$$\hat{P}_r^{ho} = \hat{P}_r^{to} + \hat{P}_r^{la} + \hat{P}_r^{kw} \quad (7)$$

with:  $\hat{P}_r^{ho}$ ,  $\hat{P}_r^{to}$ ,  $\hat{P}_r^{la}$ ,  $\hat{P}_r^{kw}$  = the average production of P in the waste waters per person for total household, toilet water, laundry washing machine and kitchenware washing machine ( $\text{kg P} \cdot \text{year}^{-1}$ ).

## Plant effluents

In areas where waste waters from households are treated in purification plants one has to deal with the removal of part of the nitrogen and phosphorus by chemical and biochemical processes. As a consequence the load on surface waters will be reduced and can be calculated as follows:

$$N_r^{ef} = f_r^{ef} (POP)_r \cdot p_n \cdot \hat{N}^{ho} \quad (\text{kg N} \cdot \text{year}^{-1}) \quad (8)$$

$$P_r^{ef} = f_r^{ef} (POP)_r \cdot p_p \cdot \hat{P}^{ho} \quad (\text{kg P} \cdot \text{year}^{-1}) \quad (9)$$

in which:

$N_r^{ef}, P_r^{ef}$  = average discharge of nitrogen and phosphorus per person in effluents from purification plants, originating from the waste water from households in region r  
 (kg N.year<sup>-1</sup>, kg P.year<sup>-1</sup>)

$f_r^{ef}$  = fraction of the population connected to the sewerage system of the purification plant considered in region r

$(POP)_r$  = size of the population in region r

$p_n, p_p$  = residual fraction for nitrogen and phosphorus in the effluents of plants ( $0 \leq p \leq 1$ )

$\hat{N}^{ho}, \hat{P}^{ho}$  = average production of N and P in the waste water from households per person (kg N.year<sup>-1</sup>, kg P.year<sup>-1</sup>)  
 (see table 1 for values)

The purification coefficient depends on the type of plant and the load situation. For the purification plant in the study area the Regional Watermanagement Authority gives values of 0.50 for P and 0.60 for N.

The fraction of the population connected to purification plants will vary from region to region depending on the distance to the plant and population density. Real values for every region r have to be collected.



## Disposal near houses

Especially in rural areas a certain fraction of the population will not be connected to purification plants. Disposal of the waste waters from households can be done in different ways depending on the origin of the waste and on the local circumstances. An inquiry in the Southern Peel region among 38 households gave information on the fate of toilet water and waters from the laundry washing machine and the kitchenware washing machine (OOSTEROM, 1983) (table 2).

Table 2. Fractions of the population not connected to purification plants which disposes the waste waters from households in a certain way

Way of disposal	Toilet water	Laundry washing machine	Kitchen ware washing machine
Discharge on local drainage system	0.05	0.45	0.25
Discharge on isolated ditch	0.0	0.10	0.05
To slurry pit	0.85	0.40	0.30
To sink pit with drainage into subsoil	0.10	0.05	0.05
Not applicable	0.0	0.0	0.35
	1.0	1.0	1.0

From the point of view of surface water quality only the direct discharges of waste water on the local drainage system are of importance. The amount of N and P which is discharged on open water is determined by the size of the population and the fraction of the population with direct discharge on open water:

$$N_r^{ho} = f_r^{to} (1 - f_r^{ef})(POP)_r \cdot \hat{N}^{to} \quad (\text{kg N} \cdot \text{year}^{-1}) \quad (10)$$

in which:

- $N_r^{ho}$  = discharged nitrogen on open water in area  $r$  from the households ( $\text{kg N.year}^{-1}$ )
- $f_r^{to}$  = fraction of the population not connected to a purification plant with direct discharge of toilet water on the local drainage canals in region  $r$  (see table 2)
- $(POP)_r$  = size of the population in region  $r$
- $\hat{N}_r^{to}$  = average production of nitrogen in the toilet water per person ( $\text{kg N.year}^{-1}$ ) (see table 1)

$$P_r^{ho} = (f_r^{to} \cdot \hat{P}_r^{to} + f_r^{la} \cdot \hat{P}_r^{la} + f_r^{kw} \cdot \hat{P}_r^{kw})(1 - f_r^{ef})(POP)_r$$

( $\text{kg P.year}^{-1}$ ) (11)

in which:

- $P_r^{ho}$  = discharged phosphorus on open water in area  $r$  from households ( $\text{kg P.year}^{-1}$ )
- $f_r^{to}, f_r^{la}, f_r^{kw}$  = fraction of the population, which is not connected to a purification plant, with direct discharge on open water of toilet water and waste waters from laundry and kitchen ware washing machines (see table 2)
- $f_r^{ef}$  = fraction of the population connected with purification plants
- $\hat{P}_r^{to}, \hat{P}_r^{la}, \hat{P}_r^{kw}$  = average production of  $P$  in the waste water flows per person ( $\text{kg P.year}^{-1}$ ) (see table 1)

### 2.3. Industrial waste waters

In certain regions industrial activities might be responsible for the production of waste water. In that case information has to be collected about the amount  $N$  and  $P$  produced and the way of treatment. In general the waste will be treated in purification plants, hence the load on surface waters can be calculated with the formula:

$$P_r^{ind} = p_p \cdot \hat{P}_r^{ind}$$

( $\text{kg P.year}^{-1}$ ) (12)

$$N_r^{ind} = p_n \cdot \hat{N}_r^{ind} \quad (\text{kg N} \cdot \text{year}^{-1}) \quad (13)$$

in which:

$P_r^{ind}, N_r^{ind}$  = load of N and P on surface waters in region r from industrial sources

$\hat{P}_r^{ind}, \hat{N}_r^{ind}$  = produced N and P in waste waters in region r from industrial sources

$p_p, p_n$  = residual fraction of N and P after treatment of the produced wastes ( $0 \leq p \leq 1.0$ )

### 3. SURFACE RUNOFF (quality)

The nutrient concentrations in the surface run-off from agricultural soils depend on many factors, among which:

- fertility status of the soil
- amount of animal manure put on the soil during the last spreading
- soil moisture condition at the time of spreading
- time elapsed between moment of spreading and surface runoff event and the amount of precipitation in that period.

The moment of spreading in a certain region will in general differ from farmer to farmer. The most important thriving force for a farmer to spread his manure in autumn and winter is the available storage capacity in relation with the amount of animal manure produced on his farm. The trafficability of the farmer's land also plays a role in the choice of the moment of spreading. In reality it can therefore be expected that the spreading of manure in a region will be rather diffuse in space and time.

The general equation for the calculation of the total input via surface run-off is:

$$N_r^{sro} = q_r^o \cdot [N^{sro}]_r \quad (14)$$

$$P_r^{sro} = q_r^o \cdot [P^{sro}]_r \quad (15)$$

in which:

- $N_r^{sro}, P_r^{sro}$  = the load of nitrogen or phosphorus on surface waters from surface run-off over a certain period in region r
- $q_r^o$  = the water discharge on surface waters from surface run-off over a certain period in region r
- $[N^{sro}]_r, [P^{sro}]_r$  = concentration of nitrogen or phosphorus in surface run-off in a certain period in region r ( $g \cdot m^{-3}$ )

The data for  $q_r^o$  will be given by the hydrological models (VAN BAKEL and SMIT, 1983).

The concentration of N and P in surface run-off can in general be calculated from:

$$[N^{sro}]_r = [N_b^{sro}]_r + a_n^{sro} \cdot \frac{\sum_{i,h} \{N_{i,h}^f(k=2) \cdot A_{i,h}\}}{A_r} \quad (16)$$

$$[P^{sro}]_r = [P_b^{sro}]_r + a_p^{sro} \cdot \frac{\sum_{i,h} \{P_{i,h}^f(k=2) \cdot A_{i,h}\}}{A_r} \quad (17)$$

in which:

- $[N_b^{sro}], [P_b^{sro}]$  = base concentration of N and P in the surface run-off in a period without fertilization ( $g \cdot m^{-3}$ )
- $a_n^{sro}, a_p^{sro}$  = conversion factor, which relates N- and P-dose in animal manure with N- en P-concentration in surface run-off. Values for  $a_n$  and  $a_p$  will differ for type of summer and type of winter (wet, dry)
- $N_{i,h}^f(k=2), P_{i,h}^f(k=2)$  = Amount of N and P in animal manure given on crop i and farm h ( $kg \cdot year^{-1}$ )
- $A_r$  = total area of region r
- $A_{i,h}$  = area with crop i on farm h

The influence of crop type on nutrient concentrations in the surface run-off is reflected in the amount of animal manure spread on the soil. In sloping areas also the difference between covered

(e.g. grass) and bare (arable land) soils might be relevant because of soil erosion. For the situation in the Netherlands soil erosion can be neglected in general compared to the influence of animal manure dose.

Occasions with surface run-off in general will occur in autumn, winter and spring. Without manuring in this period a base concentration of N and P will be measured in the surface run-off water. The base concentration for N exists mainly of ammonium and organic N.

Real values for  $c^{sro}$  in the Southern Peel study have to be deducted from the field measurements.

Equations (16) and (17) can be used in regions where the spreading of manure can and will take place throughout the year. When restrictions are imposed on the spreading in wintertime, the consequence will be an increase in the animal manure dose in springtime.

The shift in animal manure fertilization from winter to spring means increased fertilization activities in springtime and as a consequence a higher risk for the quality of surface run-off. It is assumed however that the better situation with respect to infiltration compensates for that higher risk. Restrictions might be imposed for the period from November till the end of February because of the high contributions of the amount of surface run-off and the danger of animal manure disposal on frozen soil surfaces.

For these situations the amount of nutrients lost by surface run-off can be calculated as follows for:

$$\begin{array}{l} \text{months without} \\ \text{restrictions:} \end{array} \quad N_r^{sro}(m) = q_r^o(m) \times \text{eq (16)} \quad (18)$$

$$P_r^{sro}(m) = q_r^o(m) \times \text{eq (17)} \quad (19)$$

$$\begin{array}{l} \text{months with} \\ \text{restrictions:} \end{array} \quad N_r^{sro}(m) = q_r^o(m) \times [N_b^{sro}]_r \quad (20)$$

$$P_r^{sro}(m) = q_r^o(m) \times [P_b^{sro}]_r \quad (21)$$

in which:

$m$  = month number (1 = January; 2 = February ...., 12 = December)

#### 4. INPUT WATER FROM THE CANAL

Input water from the canal might be necessary for agricultural purposes and for a nature conservation strategy. Inport of water means input of minerals, which can be calculated with:

$$N_r^{\text{in}} = q_r^{\text{in}} \cdot [N^{\text{in}}]_r \quad (22)$$

$$P_r^{\text{in}} = q_r^{\text{in}} \cdot [P^{\text{in}}]_r \quad (23)$$

in which:

$N_r^{\text{in}}, P_r^{\text{in}}$  = load of nitrogen or phosphorus on surface waters  
 from input water in region r ( $\text{kg} \cdot \text{year}^{-1}$ )  
 $q_r^{\text{in}}$  = amount of input water in region r ( $\text{m}^3 \cdot \text{year}^{-1}$ )  
 $[N^{\text{in}}]_r, [P^{\text{in}}]_r$  = concentration of nitrogen or phosphorus in  
 input water for region r ( $\text{g} \cdot \text{m}^{-3}$ )

#### 5. INPUT FROM GROUNDWATER SYSTEMS

##### 5.1. P h o s p h o r u s

The top soil has a certain capacity to fix phosphate which is in excess of the crop need. For sandy soils the iron and aluminum content determine the maximum amount of phosphate which can be stored. The displacement of the phosphate can be calculated roughly, when some simplifications are accepted (LEXMOND e.a., 1982), with the formula:

$$\delta y_{i,h} = \frac{(P_{i,h} - P_{i,h}^{\text{cr}}) \cdot 141}{B_h \cdot S_h} \quad (24)$$

in which:

$\delta y_{i,h}$  = displacement of the blockfront downwards ( $\text{cm} \cdot \text{year}^{-1}$ )  
 on farm h for crop i  
 $P_{i,h}$  = phosphate dose ( $\text{kg } P_2O_5 \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ )  
 (animal manure + artificial fertilizer) on crop i for farm h

$P_{i,h}^{cr}$  = P-uptake by crop i on farm h ( $\text{kg P}_2\text{O}_5 \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ )

$B_h$  = bulk density of the soil ( $\text{kg} \cdot \text{m}^{-3}$ )

$S_h$  = sorption capacity of the soil on farm h ( $\text{mmol P} \cdot \text{kg}^{-1}$ )

Bulk density and sorption capacity depend on soil type.

In principle two different situations are of importance with respect to groundwater and surface water quality:

1) the maximum storage capacity of the soil has not yet been reached.

The concentration of phosphate in the groundwater can be considered as a natural concentration:

$$[P^1] = [P_b^1] \quad (25)$$

in which:

$[P^1]$  = concentration of phosphorus in the groundwater, leaving the top soil and entering the saturated groundwater system ( $\text{g} \cdot \text{m}^{-3} \text{P}$ )

$[P_b^1]$  = the base concentration of phosphorus in the groundwater, which depends on more or less natural soil conditions ( $\text{g} \cdot \text{m}^{-3} \text{P}$ )

2) the maximum storage capacity of the soil has been reached. The phosphate given in excess of crop need will leach to the groundwater system:

$$[P^1] = (P_{i,h}^f - P_{i,h}^{cr}) \cdot \frac{0.44}{q_{i,h}} \quad (26)$$

in which:

$P_{i,h}^f$  = total phosphate dose on crop i for farm h ( $\text{kg P}_2\text{O}_5 \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ )

$P_{i,h}^{cr}$  = crop uptake on farm h for crop i ( $\text{kg P}_2\text{O}_5 \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ )

$q_{i,h}^1$  = amount of water entering the saturated groundwater system ( $\text{m}^3 \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ ) for crop i and farm h

For the Southern Peel study the decision can be made in one of the scenarios that overdosing of the soil can be accepted to a certain level. For fodder maize fields it can be assumed that for example in 10 years the soils will be saturated with phosphate.

In general the P input from the topsoil into the groundwater system will be:

- P storage capacity still remaining

$$P_{i,h}^1 = q_{i,h}^1 \cdot [P_b^1] \quad (27)$$

- P storage capacity consumed:

$$P_{i,h}^1 = (P_{i,h}^f - P_{i,h}^{cr}) \quad (28)$$

in which:

$P_{i,h}^1$  = P input from the top soil into the groundwater  
 for crop i on farm h ( $\text{kg P} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ )

$q_{i,h}^1$  = water input from the top soil into the saturated  
 groundwater system ( $\text{m}^3 \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ )

The input into the groundwater system in a certain year in region r amounts:

$$P_r^1 = \frac{\sum_{i,h} (P_{i,h}^1 \cdot A_{i,h})}{A_r} \quad (29)$$

and the average concentration:

$$[P^1]_r = \frac{P_r^1}{q_r^1} \quad (30)$$

in which:

$A_{i,h}$  = area of crop i on farm h (ha)

$A_r$  = area of region r (ha)

$q_r^1$  = average groundwater input from the topsoil in  
 region r in a certain year ( $\text{m}^3 \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ )

In the saturated groundwater system no significant fixation of P takes place. So the amount of P entering the groundwater will also enter the surface water system in the long run.



## 5.2. Nitrogen base leaching

The leaching of nitrogen via the groundwater system to surface water can be split up in:

- the shallow leaching from the top soil to the freatic groundwater ( $N^1$ )
- the deep leaching from the freatic groundwater to the deep groundwater and eventually to the surface water ( $N^{1d}$ ).

The shallow leaching consists of a base leaching or a background load, which depends on soil use and soil characteristics, and an additional load depending on the level of fertilization and type of fertilizer.

With soil use is meant: grassland, arable land and horticulture, forests, nature, village.

With soil characteristics in this study is meant: percentage of organic matter in the top soil and mean groundwater level in the winter period.

The potential base load of the freatic groundwater from the different soil uses can be calculated as follows:

$$\begin{aligned} Nb_r \cdot A_r = & Nb,g \cdot Ag_r + Nb,a \cdot Aa_r + Nb,f \cdot Af_r + Nb,n \cdot An_r + \\ & + Nb,v \cdot Av_r \end{aligned} \quad (31)$$

in which:

$Nb_r$  = base leaching of nitrogen to the freatic groundwater in region r at the standardized winter groundwater level of 1.25 m below soil surface

$A_r$  = total area in region r for the given soil uses (ha)

$Ag_r$ ;  $Aa_r$ ;  $Af_r$ ;  $An_r$ ;  $Av_r$  = area grassland, arable land and horticulture, forest, nature and village for region r (ha)

$Nb,g$ ;  $Nb,a$ ;  $Nb,f$ ;  $Nb,n$ ;  $Nb,v$  = base leaching of N to the freatic groundwater from grassland, arable and horticultural land, forest, nature, village ( $kg\ N \cdot ha^{-1} \cdot year^{-1}$ ) for the situation that the winter groundwater level is 1.25 m below soil surface.

Results with lysimeter experiments at the research station Sinderhoeve of the Institute have shown that the winter groundwater level plays an important role in nitrate leaching. A higher groundwater level results in a lower nitrate leaching at the same fertilization level. The influence can be quantified by:

$$Nb^1 = Nb \times f_w \quad (32)$$

in which:

- $Nb^1$  = the base leaching of nitrogen to the freatic groundwater, taking into account the winter groundwater level for a certain soil use ( $kg\ N.ha^{-1}.year^{-1}$ )
- $Nb$  = the average base leaching to the freatic groundwater for the standardized situation that the winter groundwater level is 1.25 m below soil surface ( $kg\ N.ha^{-1}.year^{-1}$ )
- $f_w$  = reduction factor for nitrogen leaching based on winter groundwater level

$$f_w = \frac{1}{1 + EXP\{-4.51(\bar{Z} - 0.685)\}} \quad (33)$$

in which:

- $\bar{Z}$  = mean groundwater level in wintertime for a certain soil use (m below soil surface)

For most soil uses a certain value can be given for the base leaching. In the case of arable land and horticulture the base leaching is assumed to be the same and is directly related to the organic matter content:

$$Nb,a = OM.20 \quad (kg\ N.ha^{-1}.year^{-1}) \quad (34)$$

in which:

- OM = organic matter content in the topsoil in % of dry matter

In reality more factors can play a role in the base leaching, for example the content of clay particles. It is assumed however that the influence of groundwater level is overwhelming the influence of other factors in sandy regions.

### 5.3. N i t r o g e n f e r t i l i z e r l e a c h i n g

The nitrogen leaching from fertilization activities is influenced by many factors:

- a) soil use (grassland, arable land, horticulture)
- b) level of fertilization
- c) type of fertilizer (artificial, animal manure)
- d) time of application
- e) climatic conditions
- f) time scale effects

For the scenario generating system the approach has to be simplified, which can be achieved as follows:

ad a) attention will be paid to:

- grassland
- arable land (including horticulture)

ad b) the level of fertilization will be taken into account

ad c) type of fertilizer is important with respect to the availability of mineral nitrogen. For artificial fertilizers all the nitrogen is in mineral form, whereas in animal manure the nitrogen is partly in organic form and partly in inorganic form. The type of animal slurry can be characterized by these fractions (tabel 3).

For example nitrogen in cattle slurry consists on average of 50% mineral N (Nm), 25% organic N which mineralises in the first year (Ne) and 25% organic N which is rather stable and mineralises slowly in the second and following years (Ns).

On the basis of field experiments data can be given for the average availability of mineral nitrogen from animal slurries

ad d) time of application will be taken into account in the following way:

- the first approach is that no restrictions are put on the spreading of manure in autumn and winter
- the second approach is that spreading of manure in autumn and winter is forbidden. Only spreading in spring or summer is allowed (see 5.4).

Table 3. Content of mineral N (Nm), decomposable organic N in first year (Ne) and residual organic N (Ns) and total N (Nt) in animal slurries and the annual slurry production

	Nt	Nm	Ne	Ns	Production
	%	%	%	%	kg.jr <sup>-1</sup> . animal <sup>-1</sup>
cattle slurry	0,44	0,22	0,11	0,11	20 200
calve slurry	0,30	0,24	0,03	0,03	2 200
pig slurry	0,55	0,28	0,18	0,09	1 600
chicken slurry	0,90	0,63	0,18	0,09	80
artificial fertilizers	16-26	16-26	0,00	0,00	-

ad e) because long term effects of fertilization will be evaluated, climatic conditions of one year are not relevant

ad f) time plays a role because of the slowly degrading organic nitrogen in slurries. In the long run the rather stable organic N fraction (Ns) will mineralize completely in one year. For this equilibrium situation the effects of slurry doses will be given. So no attention will be paid to the intermediate period before the equilibrium situation has been reached.

The total nitrogen load of groundwater resulting from fertilizer practices, including base leaching, will be given in relation with the long term available nitrogen in slurries. This means that not only the fractions Nm and Ne will be taken into account, but also the Ns fraction. Based on data from KOLENBRANDER (1981) and STEENVOORDEN (1983) and COMMISSIE VAN DE EUROPESE GEMEENSCHAPPEN (1978), the following equations for the nitrogen load of the freatic groundwater underneath grassland and arable land (and horticulture) have been developped:

$$\text{GRASS: } N_{f,g} (k=1) = 0 \quad N_f(k=1) < 250 \quad (35)$$

$$N_{f,g} (k=1) = 0.47 N_f (k=1) - 118 \quad 250 \leq N_f(k=1) < 400 \quad (36)$$

$$N_{f,g} (k=1) = 0.565 N_f (k=1) - 156 \quad 400 \leq N_f(k=1) \leq 630 \quad (37)$$

$$Nf,g (k=2) = a_g^1 \cdot Nf (k=2) \quad (38)$$

$$Nf,g = Nf,g (k=1) + Nf,g (k=2) \quad (39)$$

$$\text{ARABLE: } Nf,a (k=1) = 0.31 Nf (k=1) \quad (40)$$

$$Nf,a (k=2) = a_a^1 \cdot Nf (k=2) \quad (41)$$

$$Nf,a = Nf,a (k=1) + Nf,a (k=2) \quad (42)$$

in which:

$Nf,g$ ;  $Nf,a$  = the nitrogen leaching at a mean winter groundwater level of 1.25 m below soil surface resulting from fertilization on grassland or arable land (including horticulture) ( $\text{kg N} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ )

$Nf (k=1)$  = artificial fertilizer nitrogen applied ( $\text{kg N} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ )

$Nf (k=2)$  = animal manure nitrogen applied ( $\text{kg N} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ )

$a_g^1$ ;  $a_a^1$  = fraction of the total nitrogen applied in animal manures which leaches to the groundwater underneath grassland and arable land (values see table 4).

Table 4. Values for the fraction of N in animal manures which yearly leaches to the freatic groundwater ( $a^1$ )

Application time:	GRASSLAND				ARABLE LAND		
	grazing	march	nov.	average	march	nov.	average
cattle slurry	0,10	0,02	0,15	0,09	0,16	0,30	0,23
pig slurry	0,10	0,02	0,17	0,10	0,13	0,30	0,22
chicken slurry	0,10	0,01	0,21	0,11	0,08	0,31	0,20
calve slurry	0,10	0,01	0,23	0,12	0,05	0,31	0,18

The value for  $a^1$  in the grazing period on grassland have been taken from STEENVOORDEN (1983). The remaining values for  $a^1$  can be found in COMMISSIE VAN DE EUROPESE GEMEENSCHAPPEN (1978).

The real leaching towards the freatic groundwater can be calculated taking into account the real winter groundwater level. With the aid of eqs. (32) and (33) the real leaching can be approached by:

$$Nf_{,a}^1 = Nf_{,a} \times f_w \quad (43)$$

$$Nf_{,g}^1 = Nf_{,g} \times f_w \quad (44)$$

in which:

$Nf_{,a}^1, Nf_{,g}^1$  = the real leaching of nitrogen to the freatic groundwater from fertilization on grassland or arable land, taking into account the mean groundwater level in winter time ( $\text{kg N.ha}^{-1}.\text{year}^{-1}$ )

Total real leaching of nitrogen to the freatic groundwater system in a certain area is the summation of base leaching and leaching from fertilizers. Equations needed for these calculations are: (31), (32), (39), (42), (43), (44):

$$N_r^1 = \frac{Nb_r^1 A_r + Nf_{,g,r}^1 Ag_r + Nf_{,a,r}^1 Aa_r}{A_r} \quad (45)$$

in which:

$N_r^1$  = total average nitrogen leaching to the freatic groundwater in area r ( $\text{kg N.ha}^{-1}.\text{year}^{-1}$ )

The nitrogen concentration in the freatic groundwater can be calculated from the nitrogen load and the water input into the freatic groundwater system from the precipitation surplus. This concentration can be calculated for each type of soil use, but also for the area as a whole; for example:

$$[N^1]_{g,r} = \frac{Ng_r^1}{qg_r} \quad (46a)$$

$$[N^1]_{a,r} = \frac{Na_r^1}{qa_r} \quad (46b)$$

$$[N^1]_r = \frac{N_r^1}{qr^1} \quad (47)$$

in which:

$[N^1]_{g_r}$  = nitrogen concentration in the leachate from grassland  
 in area r ( $\text{g.m}^{-3}\text{N}$ )  
 $[N^1]_r$  = average nitrogen concentration of the leachate over  
 the whole area r ( $\text{g.m}^{-3}\text{N}$ )  
 $q_{g_r}^1, q_r^1$  = amount of water entering the freatic groundwater  
 system from precipitation surplusses for grassland  
 in region r and for region r as a whole ( $\text{m}^3.\text{ha}^{-1}.\text{year}^{-1}$ )

#### 5.4. Nitrogen processes in groundwater systems

Nitrogen leaching nearly completely takes place in the form of nitrate. During transport in the groundwater system nitrate can be reduced by biochemical denitrification when circumstances are favourable for this process. The end products,  $\text{N}_2$  and/or  $\text{N}_2\text{O}$ , will be transported to the atmosphere. The amount of nitrate which can be broken down depends on the denitrification capacity of the sediments and the residence time in those sediments.

Denitrification capacity is related tot the organic matter content and moreover is influenced by the pH-value of the groundwater. Organic matter can be available from the sediment itself or it can be transported downwards from the rootzone. This last fraction is only a restricted amount. The most important organic carbon source for denitrification is the native organic carbon in the sediment.

The deep lysimeter experiment at Sinderhoeve has shown that the denitrification capacity for a sandy soil with  $\text{pH} = 6$ , organic matter content = 0,9% and groundwater temperature =  $10^\circ\text{C}$  amounts  $160 \text{ kg N.ha}^{-1}$  for 1 year residence time. Under optimal pH conditions ( $\text{pH}=7$ ) the denitrification rate for a sandy soil with 1,0% organic matter amounts roughly  $240 \text{ kg N.ha}^{-1}.\text{year}^{-1}$ . The real denitrification in the sediment can be calculated as follows:

$$Nd_r^1 = OM_r^1 \cdot 240 \cdot f(pH)_r^1 \cdot T_r^1 \quad (\text{kg N.ha}^{-1}) \quad (48)$$

in which:

$Nd_r^1$  = amount of nitrate nitrogen denitrified in the groundwater system of aquifer 1 in region r ( $\text{kg N.ha}^{-1}$ )

$OM_r^1$  = percentage organic matter in aquifer 1 of region r

$f(pH)_r^1$  = correction factor for the influence of pH in aquifer 1 of region r

$T_r^1$  = residence time of groundwater in region r for the 1st aquifer(will be given by VAN BAKEL and SMIT (1983))

$$f(pH)_r^1 = \frac{1}{1 + \text{EXP}\{-1.916(\text{pH}-5.457)\}}$$

The precipitation surplusses will be transported to the drainage ditches and canals. The load which reaches surface waters via the 1st aquifer is the result of leaching and denitrification:

$$N_r^{1d} = N_r^1 - Nd_r^1 \quad (49)$$

in which:

$N_r^{1d}$  = the nitrogen load on surface waters after deep leaching via the 1st aquifer in region r ( $\text{kg N.ha}^{-1}.\text{jr}^{-1}$ )

## 6. TOTAL LOAD ON SURFACE WATERS

The total load on surface waters can be calculated as a result of the input from all sources. The relevant sources can be quantified in the chapters which deal with a certain source. Fig. 1 gives an overview of all sources which are taken into account. For regions with a large area of surface waters attention should be paid to the direct input of nitrogen and phosphorus from precipitation.

Nitrogen and phosphorus are involved in chemical and biochemical processes in the surface waters. Examples of these processes are: uptake by water weeds, phosphate precipitation with iron, dissolution of phosphate, denitrification and volatilization. These processes



are not taken into account in this approach, although they might influence water quality to a large extent in summertime because of the longer residence. As roughly 90% of the N and P load takes place in the winter half-year with short residence times this influence is ignored.

The summation is easy to be done for sources like: plant effluents, waste waters from households, dairy farms and industry, input water from the canal. Summation is more difficult for inputs from soil and groundwater because of the complex flow pattern of precipitation surplusses in relation with the drainage situation. Based on response time of water discharge upon precipitation, difference can be made between:

- $q^0$  = surface runoff: short contact with the top-soil
- upper groundwater flow: short residence time in the saturated groundwater system which could be named  $q^1$  (fast)
- deep groundwater flow: residence time in the saturated groundwater system longer than roughly some months:  $q^1$  (slow)

For the set of equations developed in this report this differentiation is of importance only for nitrogen because of the influence of residence time on denitrification. So hydrological calculations will have to split up  $q^1$  in some areas in a fast and a slow component. These components will have to be combined with a water quality component, which could be done in the following way:

$$N_r^1 \text{ (fast)} = q_r^1 \text{ (fast)} \times [N^1]_r \quad (\text{see eq. 47}) \quad (50)$$

$$N_r^1 \text{ (slow)} = q_r^1 \text{ (slow)} \times [N^{1d}]_r \quad (\text{see eq. 49}) \quad (51)$$

Concentrations in the surface waters can be calculated from the total N and total P load and the water discharges. Waste waters from dairy farms and isolated houses can be ignored with respect to water quantity.

$$q_r^{sr} = q_r^0 + q_r^1 \text{ (fast)} + q_r^1 \text{ (slow)} + q_r^{in} + q_r^{ind} + q_r^{ef} \quad (52)$$

in which:

$q_r^{sr}$  = total amount of surface water in region  $r$  ( $m^3$ )

$q_r^{in}$  = total amount of input water from the canal (")

$q_r^{ind}$  = amount of industrial waste waters (")

$q_r^{ef}$  = amount of effluent water from purification plants ( $m^3$ )

## 7. SUMMARY

Nutrient loads on surface and ground waters is the result of inputs from various sources. For the development of a plan for water management information is needed about the consequences of alternative scenarios. Therefore mathematical approaches have been developed for the contributions by the polluting sources. In this report equations are given to make estimates of the nitrogen and phosphorus load originating from waste water discharges, input water from canals and fertilizing activities in agriculture. Partly the parameter values needed in the equations are already available, partly they will have to be collected from field data in the Southern-Peel study.

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